

```

%
%***** small_network_mcmc.m *****
%
%
% This program utilizes a Markov Chain Monte Carlo
% method for the prediction of the most likely configuration
% or state of a regulatory network.
%
%
% smg - Last Modified: 8/7/00

frame_count = 0;
rejected = 0;
edge_number(1,1) = 0;

% Ask user for set-up information
configuration = input('Starting from scratch (0) or from an initial Adjacency mtx (1):
');
if configuration == 1
    A_dir = input('Enter path and filename for Adjacency matrix:');
else
    initial_edges = input('Input initial number of edges: ');
end
input_dir = input('Enter directory for probability matrices: ');
iterations = input('Input number of iterations: ');
burn_in = input('Enter number of burn-in iterations: ');
directory = input('Enter directory of input files in single quotes: ');
ks = input('Enter maximum number of edges to sample(change) at one time: ');
save_interval = input('Enter save interval: ');

%
%
% Load precalculated arrays
cd(input_dir);
load edge_matrix; % used for sampling edges
load edge_probabilities;
probarray = edge_probabilities; % probability of an edge
clear edge_probabilities;
load edge_probabilities_zero
probarray_zero = edge_probabilities_zero; % probability of not having edge
clear edge_probabilities_zero;

% Load look-up table for ln of factorial
load lnfac.txt -ascii;
lnfac = reshape(lnfac',10008,1);

% Load data
cd(directory);
names = dir;

% get vertices
for n = 3:length(names); %3-708(Curagen) 3-13(test) 3-641(DIP) - process each file
    filename = names(n).name;
    datain = load(filename);
    protein(n-2).id = n-2;
    newname = strtok(filename, '.');
    newname = str2num(newname);
    protein(n-2).name = newname;
    protein(n-2).domains = datain(1:end);
    idnamelist(n-2) = newname;
end

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end
len = length(idnamelist);          % number of vertices

edge_freq = sparse(len,len);

% Set up random edges between vertices
if configuration == 0
    A = sparse(len,len);
    for i = 1:initial_edges
        i_init = 1 + floor(rand*len);
        j_init = 1 + floor(rand*len);
        A(i_init,j_init) = 1;
    end
else
    % must be called Alast - Make more user friendly
    load(A_dir);
    A = Alast; % A = Alast;
    clear Alast;
end

edgesinit = nnz(A)                % number of interactions
edgevector = sum(A,2);            % number of outgoing edges for each vertex
inedgevector = sum(A);            % number of incoming edges for each vertex
edge_number(1,1) = edgesinit;

% Calculate edge probabilities
% prob_edges is the sum of log(prob) for each existing edge
% prob_edges_zero is the sum of log(prob) for each non-existent edge
prob_edges = 0;
prob_edges_zero = 0;
for i = 1:len
    for j = 1:len
        if A(i,j) == 1
            prob_edges = prob_edges + log(probarray(i,j));
        else
            prob_edges_zero = prob_edges_zero + log(probarray_zero(i,j));
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Calculate system probability %%%%%%%%%%%%%%%
LOGPTRANS = prob_edges;
LOGPTRANSzero = prob_edges_zero;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Incoming edge probability - Multinomial
% Determine the number of vertices with 0,1,... incoming edges
invertexedgevect = zeros(1,max(inedgevector)+1);
for i = 1:length(inedgevector)      % i = 1 is vert w/ zero incoming edges
    invertexedgevect(inedgevector(i)+1) = invertexedgevect(inedgevector(i)+1) + 1;
end

% Multinomial dist.
MIN = sum(invertexedgevect);        % Total number of vertices
LOGPIN = 0;
LOGDENIN = 0;
for i = 1:length(invertexedgevect)
    LOGPIN = LOGPIN + invertexedgevect(i)*log(probinedge(i-1));
    LOGDENIN = LOGDENIN + lnfac(invertexedgevect(i)+ 1);
end
LOGNUMIN = lnfac(MIN+1);

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##### Outgoing edge probability - Multinomial
% Determine the number of vertices with 0,1,.. outgoing edges
vertexedgevect = zeros(1,max(edgevector)+1);
for i = 1:length(edgevector)      % i = 1 is vertex w/ 0 outgoing edges
    vertexedgevect(edgevector(i)+1) = vertexedgevect(edgevector(i)+1) + 1;
end

% Multinomial dist.
M = sum(vertexedgevect);          % Total number of vertices (= MIN)
LOGPOUT = 0;
LOGDEN = 0;
for i = 1:length(vertexedgevect)
    LOGPOUT = LOGPOUT + vertexedgevect(i)*log(edgedist(i-1));
    LOGDEN = LOGDEN + lnfac(vertexedgevect(i)+ 1);
end
LOGNUM = lnfac(M+1);
LOGDEN;
LOGPOUT;

#####
% Likelihood of system in initial configuration
LOGSYSX = (LOGNUM-LOGDEN)+LOGPOUT+(LOGNUMIN-LOGDENIN)+LOGPIN+LOGPTRANS+LOGPTRANSzero;
fprintf('Initial Probability = %5.4E\n\n',LOGSYSX)

% Save initial configuration - for reference
LOGSYSXorig = LOGSYSX;
Aorig = A;
edgevectororig = edgevector;
inedgevectororig = inedgevector;
vertexedgevectororig = vertexedgevect;
invertedgevectororig = invertedgevect;

#####
% Add or remove edge at random & recompute likelihood

flag = 1;          % for testing purposes
if flag == 1;

prob_edgescomp = prob_edges;
prob_edges_zerocomp = prob_edges_zero;
edgevectorcomp = edgevector;
inedgevectorcomp = inedgevector;
Acomp = A;

% set up matrix for observing frequency of edge sampling
edge_freq = zeros(len,len);

#####
tic;
for x = 1:iterations
    % choose to add or remove
    if rand < 0.5
        #####
        % add edge
        #####

        % create A0 matrix
        A0 = (A==0);
    end
end

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% select edge from those that are currently = 0
[edges,q_x2y,q_y2x] = edge_selection(ks,A0,lnfac);

[edge_rows,edge_cols] = size(edges);
% update parameters
for t = 1:edge_rows
    A(edges(t,1),edges(t,2)) = 1;
    prob_edges = prob_edges + log(probarray(edges(t,1),edges(t,2)));
    prob_edges_zero = prob_edges_zero - log(probarray_zero(edges(t,1),edges(t,2)));
    edgevector(edges(t,1)) = edgevector(edges(t,1)) + 1; % update edge vectors
    inedgevector(edges(t,2)) = inedgevector(edges(t,2)) + 1;
    edge_freq(edges(t,1),edges(t,2)) = edge_freq(edges(t,1),edges(t,2)) + 1;
end

% flag showing state
add_edge = 1;

else
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % remove an edge
    % select preferentially from proteins that should be less well connected
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

    % select edge to remove
    [edges,q_x2y,q_y2x] = edge_selection(ks,A,lnfac);

    % change edge
    [edge_rows,edge_cols] = size(edges);

    % update parameters
    for t = 1:edge_rows
        A(edges(t,1),edges(t,2)) = 0;
        prob_edges = prob_edges - log(probarray(edges(t,1),edges(t,2)));
        prob_edges_zero = prob_edges_zero + log(probarray_zero(edges(t,1),edges(t,2)));
        edgevector(edges(t,1)) = edgevector(edges(t,1)) - 1;
        inedgevector(edges(t,2)) = inedgevector(edges(t,2)) - 1;
        edge_freq(edges(t,1),edges(t,2)) = edge_freq(edges(t,1),edges(t,2)) + 1;
    end

    % flag showing state
    add_edge = 0;

end

%%%%%%%%%%
% Essentially, a repeat of initial system probability calculation

LOGPTRANSY = prob_edges; % sum of transition probabilities for
LOGPTRANSzeroY = prob_edges_zero; % new system (w/ or w/o new edge)

%%%%%%%%%%
% Incoming edge probability
invertedgenew = zeros(1,max(inedgevector)+1); % # of vert. w/ 0,1,...edges
for i = 1:length(inedgevector) % i = 1 -> vert w/ 0 incoming edges
    invertedgenew(inedgevector(i)+1) = invertedgenew(inedgevector(i)+1) + 1;
end

MINY = sum(invertedgenew); % Calc Multinomial
LOGPINY = 0;

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LOGDENINY = 0;
for i = 1:length(invertedgenew)
    LOGPINY = LOGPINY + invertedgenew(i)*log(probededge(i-1));
    LOGDENINY = LOGDENINY + lnfac(invertedgenew(i)+ 1);
end
LOGNUMINY = lnfac(MINY+1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Outgoing edge probability
vertedgenew = zeros(1,max(edgevector)+1);
for i = 1:length(edgevector)
    vertedgenew(edgevector(i)+1) = vertedgenew(edgevector(i)+1) + 1;
end

MY = sum(vertedgenew);      % Calc Multinomial
LOGPOUTY = 0;
LOGDENY = 0;
for i = 1:length(vertedgenew)
    LOGPOUTY = LOGPOUTY + vertedgenew(i)*log( edgedist(i-1));
    LOGDENY = LOGDENY + lnfac(vertedgenew(i)+ 1);
end
LOGNUMY = lnfac(MY+1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Probability of new configuration
LOGSYSY = (LOGNUMY-LOGDENY)+LOGPOUTY+(LOGNUMINY-
LOGDENINY)+LOGPINY+LOGPTRANSY+LOGPTRANSzeroY;

% Check if iterations>burn_in & establish plotting interval based on
% the number of edges existing after burn in
if x == burn_in
    %save_interval = nnz(A);
    %Astart = A;
    Asave = A;
    saves = 1;
    SYSVECT(saves,1) = x;
    SYSVECT(saves,2) = LOGSYSX;
    edge_number(1,saves)=nnz(A);
    frame_count = 1;
    frame(frame_count).adj = Asave;
    frame(frame_count).edge_num = nnz(A);
end

% Save configuration after every 'save_interval' iterations
if x > burn_in & rem(x,save_interval) == 0
    Asave = Asave + A;
    saves = saves + 1;
    SYSVECT(saves,1) = x;
    SYSVECT(saves,2) = LOGSYSX;
    edge_number(1,saves) = nnz(A);
end

% Save "frames" for animation of edge probabilities
if x > burn_in & rem(x,200*save_interval) == 0
    frame_count = frame_count + 1;
    frame(frame_count).adj = Asave;
    frame(frame_count).edge_num = nnz(A);
end

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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% probability of accepting edge
paccept = exp((LOGSYSY + q_y2x) - (LOGSYSX + q_x2y));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

if rand <= paccept                % decide whether or not to keep change
    % keep change
    Acomp = A;
    edgevectorcomp = edgevector;
    inedgevectorcomp = inedgevector;
    prob_edgescomp = prob_edges;
    prob_edges_zerocomp = prob_edges_zero;

    fprintf('%5.0d\t paccept=%3.2E\t Edges=%4d\n LOGOLD=%5.4E\t LOGNEW=%5.4E\t Diff=%5.4E\n',
x, paccept, nnz(A), LOGSYSX, LOGSYSY, LOGSYSY-LOGSYSX)
    fprintf('q_x2y= %5.4E\t q_y2x= %5.4E\n\n', q_x2y, q_y2x)

    LOGSYSX = LOGSYSY;

    % update sampling distributions appropriately when an edge is added
    % or removed

else
    % proposed addition or removal of edge is not accepted
    rejected = rejected + 1;
    A = Acomp;                % reset values to that of the previous iteration
    edgevector = edgevectorcomp;
    inedgevector = inedgevectorcomp;
    prob_edges = prob_edgescomp;
    prob_edges_zero = prob_edges_zerocomp;
end
end
end
end;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%save d:\apps\matlabr11\work\dipdata\Astart.mat Astart;
%save d:\apps\matlabr11\work\dipdata\Asave.mat Asave;

rejected/iterations                % percent of changes rejected
nnz(A)
%figure;
%gplot(Abest,nodeloc,'-o');

clear Acomp;
clear A0;

figure;
plot(SYSVECT(:,1),SYSVECT(:,2));    % Plot system probability at each 'save_interval'
xlabel('Iteration Number')
ylabel('Log(L)')
title(['MCMC test - ',date])
%text(14000,-1608,'1500 edges-start, ### edges-end, s = 0.025, 50% Rejection')

figure;
pcolor(Asave./saves);
shading interp
colorbar('v')
xlabel('Vertex')

```

```
ylabel('Vertex')
title('Fraction of Time Edge is Occupied')
```

```
figure;
plot(edge_number)
xlabel('Save Number')
ylabel('Number of Edges')
```

```
figure;
pcolor(edge_freq);
shading interp
colorbar('v')
title('Frequency of Edge Sampling');
```

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function [out,q_x2y,q_y2x] = edge_selection(ks,A,lnfac)
%
%   out = edge_selection(ks,A,lnfac)
%
%   This program is used for randomly selecting edges
%   from an adjacency matrix.
%
%   Input A is an adjacency (or inverse adjacency) matrix.
%   'ks' is the maximum number of edges to be sampled.
%

len = length(A);
total_edges = len*len;

% find all 1's in A
[source,target] = find(A==1);

% number of interactions available for sampling
edges_avail = length(source);

% number of edges to be sampled
edges_sampled = 1 + floor(rand*ks);    %rand*edges_avail

% make sure you don't sample from more than available
if edges_sampled > edges_avail
    edges_sampled = edges_avail;    %useful only for ks case
end

% mix edges to be sampled
choose_from_this = randperm(edges_avail);

% Sample edges from 1 to edges_sampled
out = zeros(edges_sampled,2);    %initialize out
out(:,1) = source(choose_from_this(1:edges_sampled));
out(:,2) = target(choose_from_this(1:edges_sampled));

% Calculate the proposal distribution from new to old and old to new
qx = 0;
qy = 0;
opp_edges = total_edges - edges_avail + edges_sampled;

for i = 1:edges_sampled
    qx = qx + log((edges_sampled - i + 1)/(edges_avail - i + 1));
    qy = qy + log((edges_sampled - i + 1)/(opp_edges - i + 1));
end
q_x2y = qx;

q_y2x = qy;

```



```

function [out,q_x2y,q_y2x] = edge_selection_old(ks,A,lnfac)
%
%   out = edge_selection_old(ks,A,lnfac)
%
%   This program is used for randomly selecting edges
%   from an adjacency matrix.
%
%   Input A is an adjacency (or inverse adjacency) matrix.
%   'ks' is the maximum number of edges to be sampled.
%

len = length(A);
total_edges = len*len;

% find all 1's in A
[source,target] = find(A==1);

% number of interactions available for sampling
edges_avail = length(source);

% number of edges to be sampled
edges_sampled = 1 + floor(rand*ks);    %rand*edges_avail

% make sure you don't sample from more than available
if edges_sampled > edges_avail
    edges_sampled = edges_avail;    %useful only for ks case
end

% sample interactions available and place x and y coordinates in "out"
out = zeros(edges_sampled,2);    %initialize out
[rows,cols] = size(out);
i = 1;
while i <= edges_sampled
    x = 1 + floor(rand*edges_avail);    % pick vertex
    for n = 1:rows
        if intersect([source(x),target(x)],out,'rows')
            % sampling previously sampled point
            % try another
            break;
        else
            % previously unsampled - place in out matrix
            out(i,1) = source(x);
            out(i,2) = target(x);
            i = i + 1;
        end
    end
end
end
out;

% Calculate the proposal distribution from new to old
qx = 0;
qy = 0;
opp_edges = total_edges - edges_avail + edges_sampled;

for i = 1:edges_sampled
    qx = qx + log((edges_sampled - i + 1)/(edges_avail - i + 1));
    qy = qy + log((edges_sampled - i + 1)/(opp_edges - i + 1));
end
q_x2y = qx;
q_y2x = qy;

```

```

function [out,q_x2y,q_y2x] = edge_selection(ks,A,lnfac)
%
%   out = edge_selection(ks,A,lnfac)
%
%   This program is used for randomly selecting edges
%   from an adjacency matrix.
%
%   Input A is an adjacency (or inverse adjacency) matrix.
%   'ks' is the maximum number of edges to be sampled.
%

len = length(A);
total_edges = len*len;

% find all 1's in A
[source,target] = find(A==1);

% number of interactions available for sampling
edges_avail = length(source);

% number of edges to be sampled
edges_sampled = 1 + floor(rand*ks);    %rand*edges_avail

% make sure you don't sample from more than available
if edges_sampled > edges_avail
    edges_sampled = edges_avail;    %useful only for ks case
end

% mix edges to be sampled
choose_from_this = randperm(edges_avail);

% Sample edges from 1 to edges_sampled
out = zeros(edges_sampled,2);    %initialize out

out(:,1) = source(choose_from_this(1:edges_sampled));
out(:,2) = target(choose_from_this(1:edges_sampled));

% Calculate the proposal distribution from new to old and old to new
qx = 0;
qy = 0;
opp_edges = total_edges - edges_avail + edges_sampled;

for i = 1:edges_sampled
    qx = qx + log((edges_sampled - i + 1)/(edges_avail - i + 1));
    qy = qy + log((edges_sampled - i + 1)/(opp_edges - i + 1));
end
q_x2y = qx;

q_y2x = qy;

```

```

function [out,q_x2y,q_y2x] = edge_selection_old(ks,A,lnfac)
%
%   out = edge_selection_old(ks,A,lnfac)
%
%   This program is used for randomly selecting edges
%   from an adjacency matrix.
%
%   Input A is an adjacency (or inverse adjacency) matrix.
%   'ks' is the maximum number of edges to be sampled.
%

len = length(A);
total_edges = len*len;

% find all 1's in A
[source,target] = find(A==1);

% number of interactions available for sampling
edges_avail = length(source);

% number of edges to be sampled
edges_sampled = 1 + floor(rand*ks);    %rand*edges_avail

% make sure you don't sample from more than available
if edges_sampled > edges_avail
    edges_sampled = edges_avail;    %useful only for ks case
end

% sample interactions available and place x and y coordinates in "out"
out = zeros(edges_sampled,2);    %initialize out
[rows,cols] = size(out);
i = 1;
while i <= edges_sampled
    x = 1 + floor(rand*edges_avail);    % pick vertex
    for n = 1:rows
        if intersect([source(x),target(x)],out,'rows')
            % sampling previously sampled point
            % try another
            break;
        else
            % previously unsampled - place in out matrix
            out(i,1) = source(x);
            out(i,2) = target(x);
            i = i + 1;
        end
    end
end
out;

% Calculate the proposal distribution from new to old
qx = 0;
qy = 0;
opp_edges = total_edges - edges_avail + edges_sampled;

for i = 1:edges_sampled
    qx = qx + log((edges_sampled - i + 1)/(edges_avail - i + 1));
    qy = qy + log((edges_sampled - i + 1)/(opp_edges - i + 1));
end
q_x2y = qx;
q_y2x = qy;

```

```

function prob = edgedist(numedges)
%
% This function takes as input the number of outgoing
% edges from a vertex and returns the probability of
% this as "prob"
%
% Based on fits to experimental data
%
% smg - Last Modified: 7/22/00
%

if numedges == 0
    prob = 0.489751;
else
    prob = 0.304647*numedges.^(-1.9691);
end

```

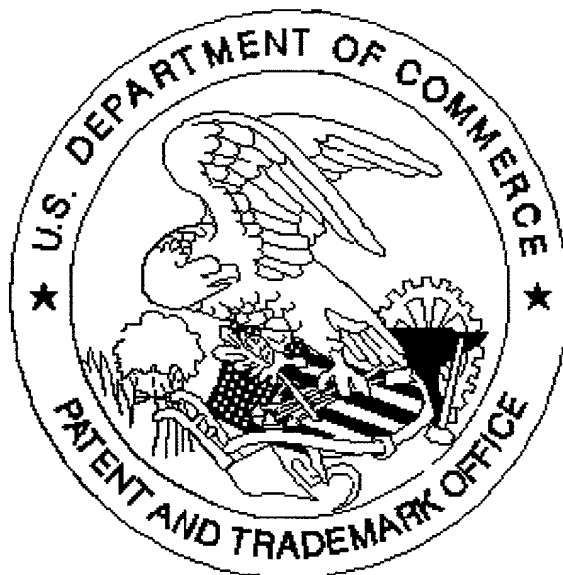
100
 90
 80
 70
 60
 50
 40
 30
 20
 10
 0

```
function y = probinedge(numedges)
%
%
%
%
%

if numedges == 0
    y = 0.306735;
else
    y = 0.556352*numedges.^(-2.8037);
end
```

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